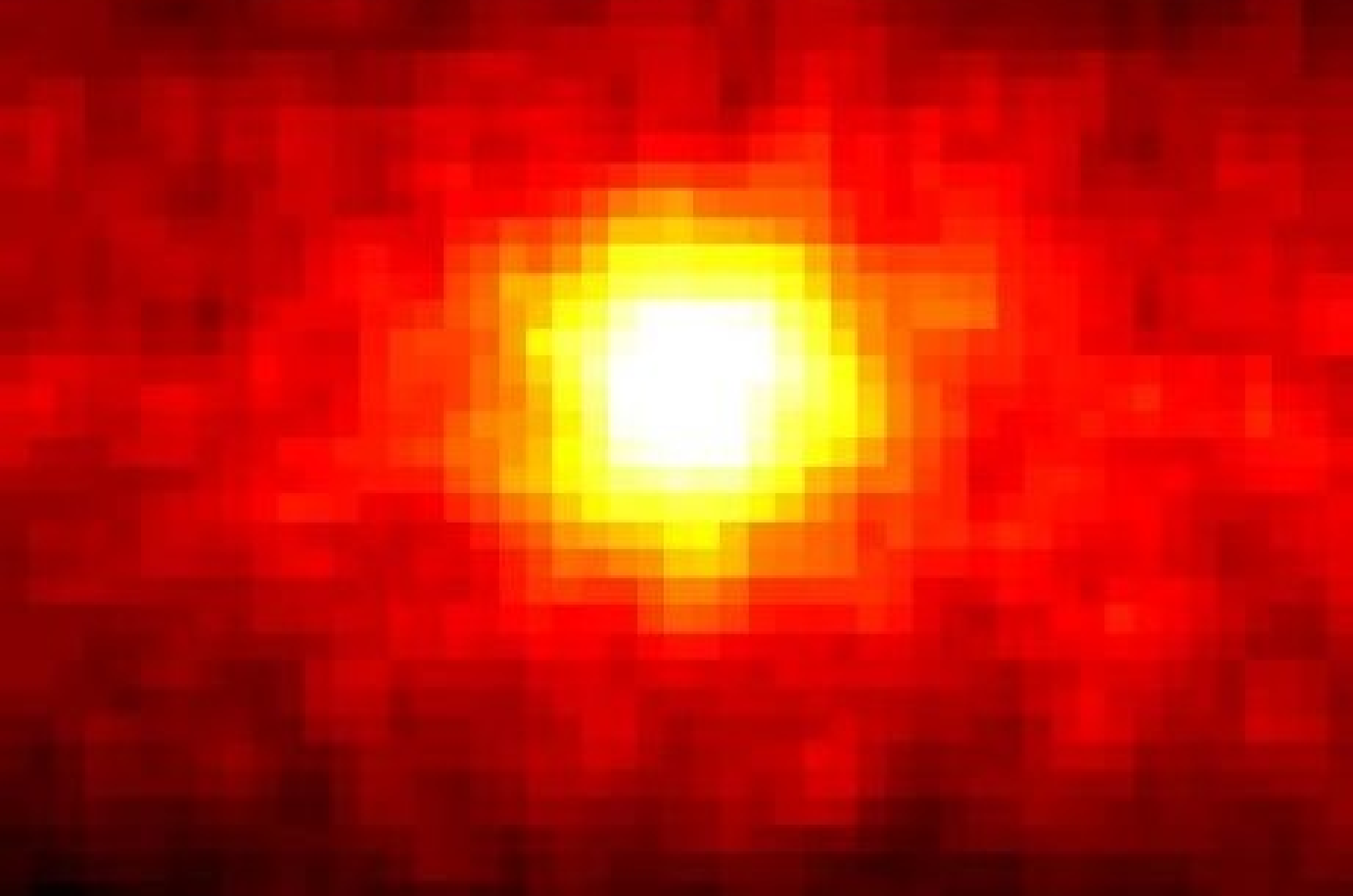
# The Sun & us



## Table 15.1 Basic Properties of the Sun

| | |
|---|---|
| Radius ($R_{Sun}$) | 696,000 km (about 109 times the radius of Earth) |
| Mass ($M_{Sun}$) | $2 \times 10^{30}$ kg (about 300,000 times the mass of Earth) |
| Luminosity ($L_{Sun}$) | $3.8 \times 10^{26}$ watts |
| Composition (by percentage of mass) | 70% hydrogen, 28% helium, 2% heavier elements |
| Rotation rate | 27 days (equator) to 31 days (poles) |
| Surface temperature | 5,800 K (average); 4,000 K (sunspots) |
| Core temperature | 15 million K |

# Big Numbers

Every human: ~2 kW (fridge~600W)

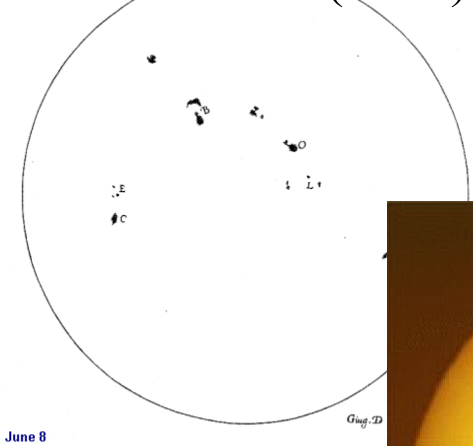
x 6 Billion humans: ~12 TW

Sun: $\sim 4 \times 10^{26}$ W

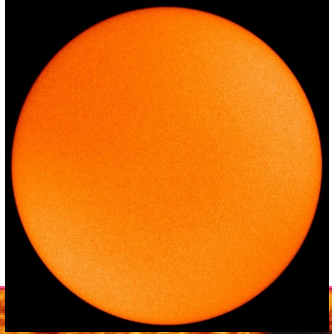
1 s of Sun enough for $\sim 3 \times 10^{13}$ s

or ~1 million yr

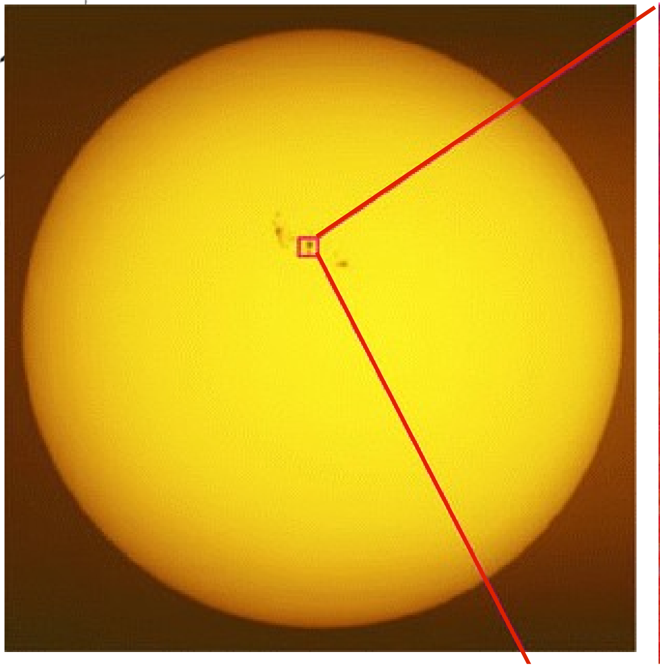
Galileo's view (1610)

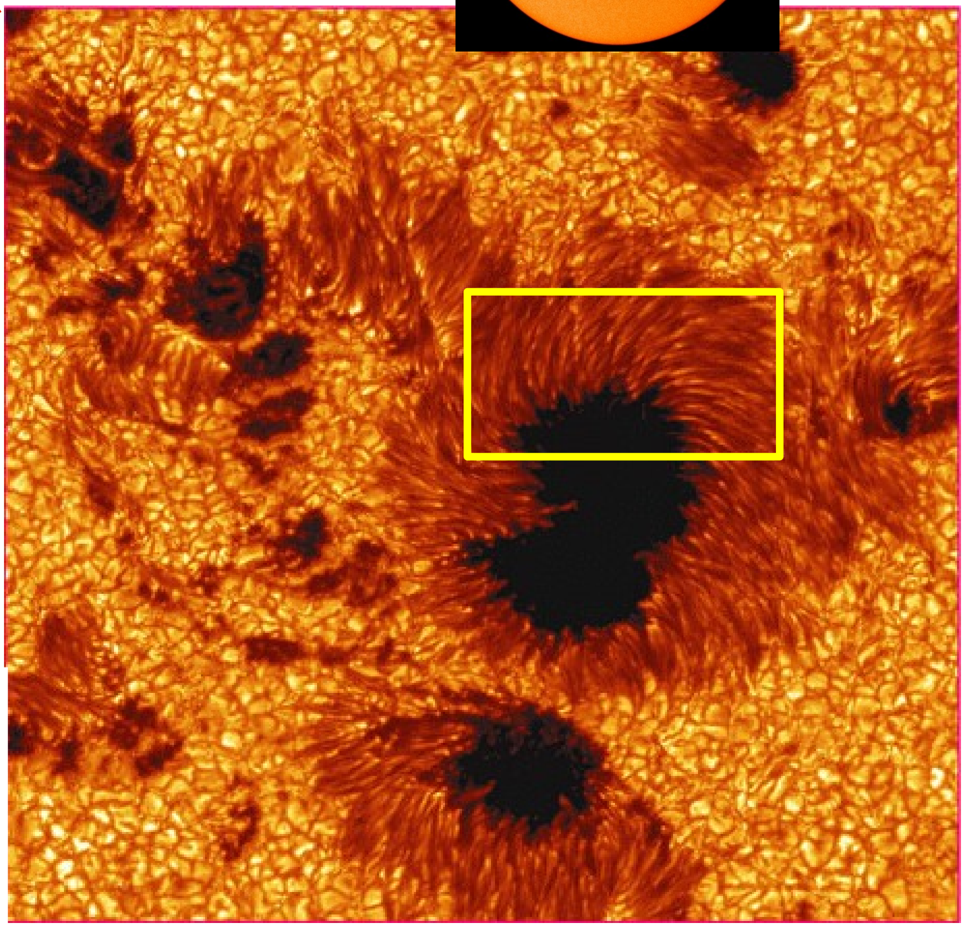



# Sunspots



*No sunspot today*

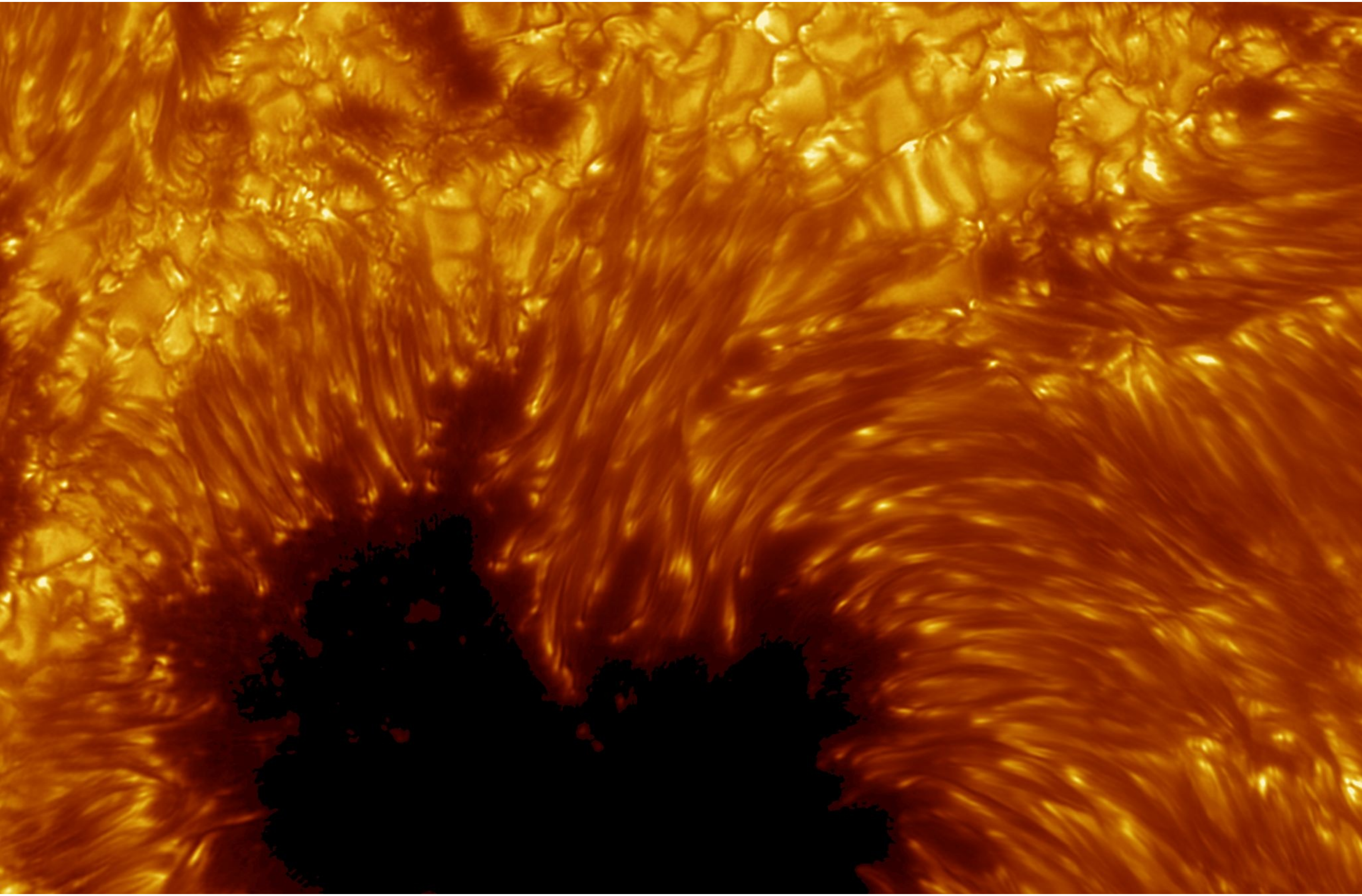




Average solar surface temperature ~ 5800 K
in the sunspot area, T ~ 4000 K *colder --> darker*

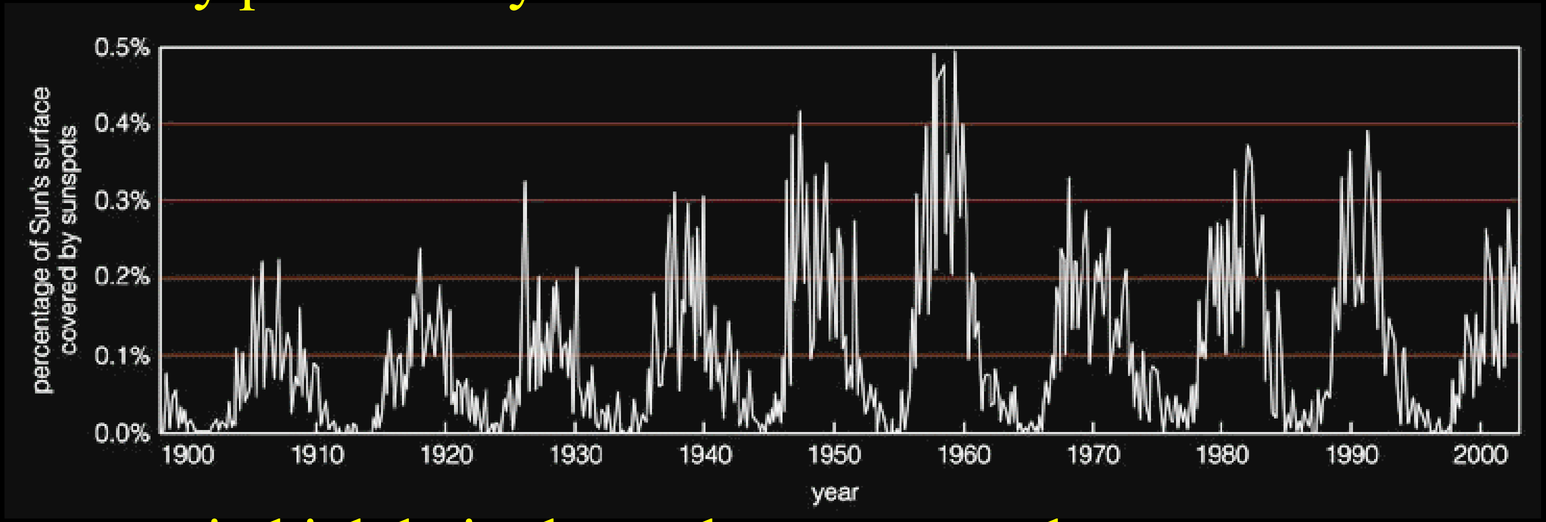
gas is strongly magnetized inside sunspots
more sunspot – higher solar magnetic activities

# Best-view-ever of a sunspot (Swedish solar telescope, movie)

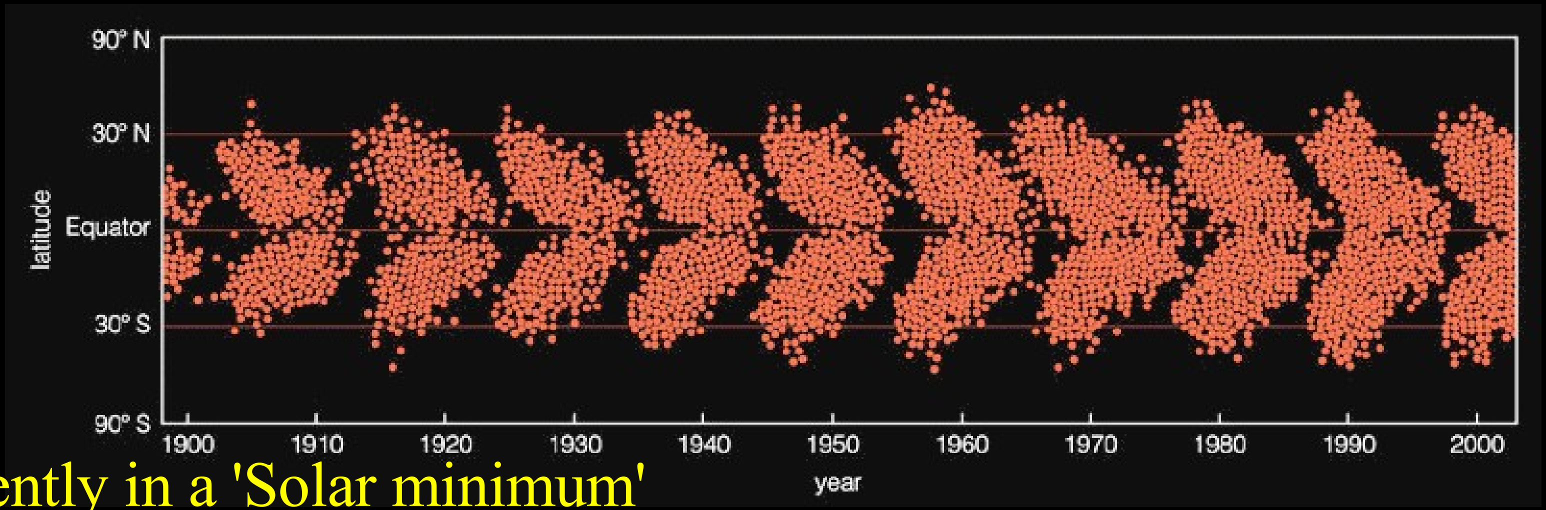


# Sunspot activities cycle every ~ 11 years (solar cycle)

1) sunspot numbers vary periodically

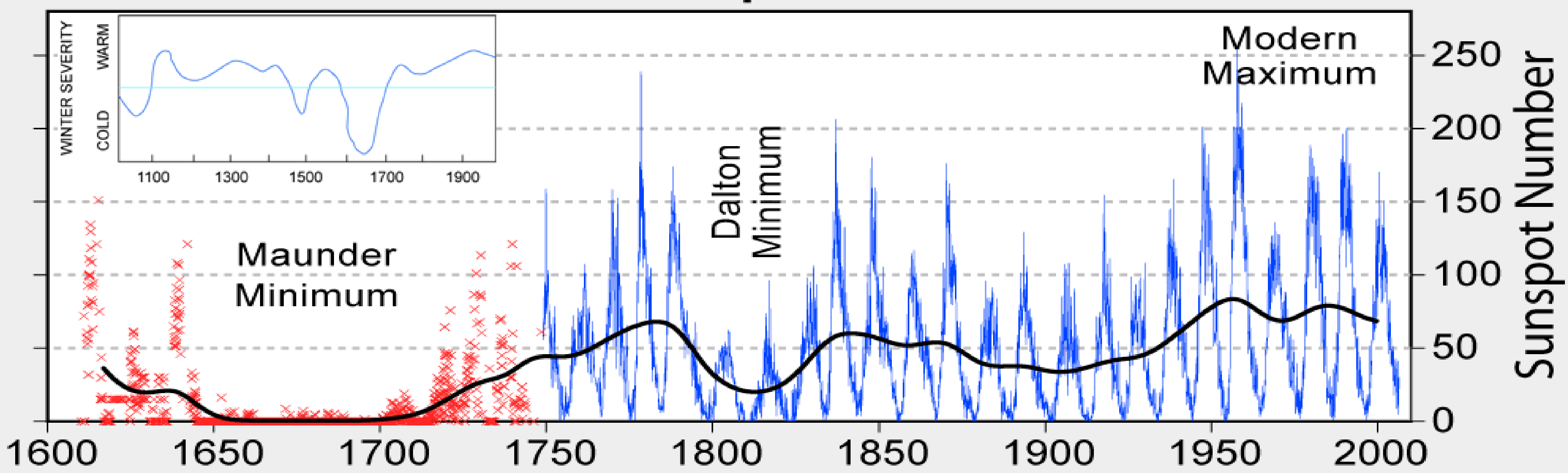



2) sunspots first appear in high latitudes and move toward the solar equator during this cycle




3) we are currently in a 'Solar minimum'

# 400 Years of Sunspot Observations




Between 1645AD-1715AD, the sunspot numbers go through a minimum.

This 'Maunder Minimum' coincides with unusually cold winters in Europe and around (average T lower by up to 1 deg)

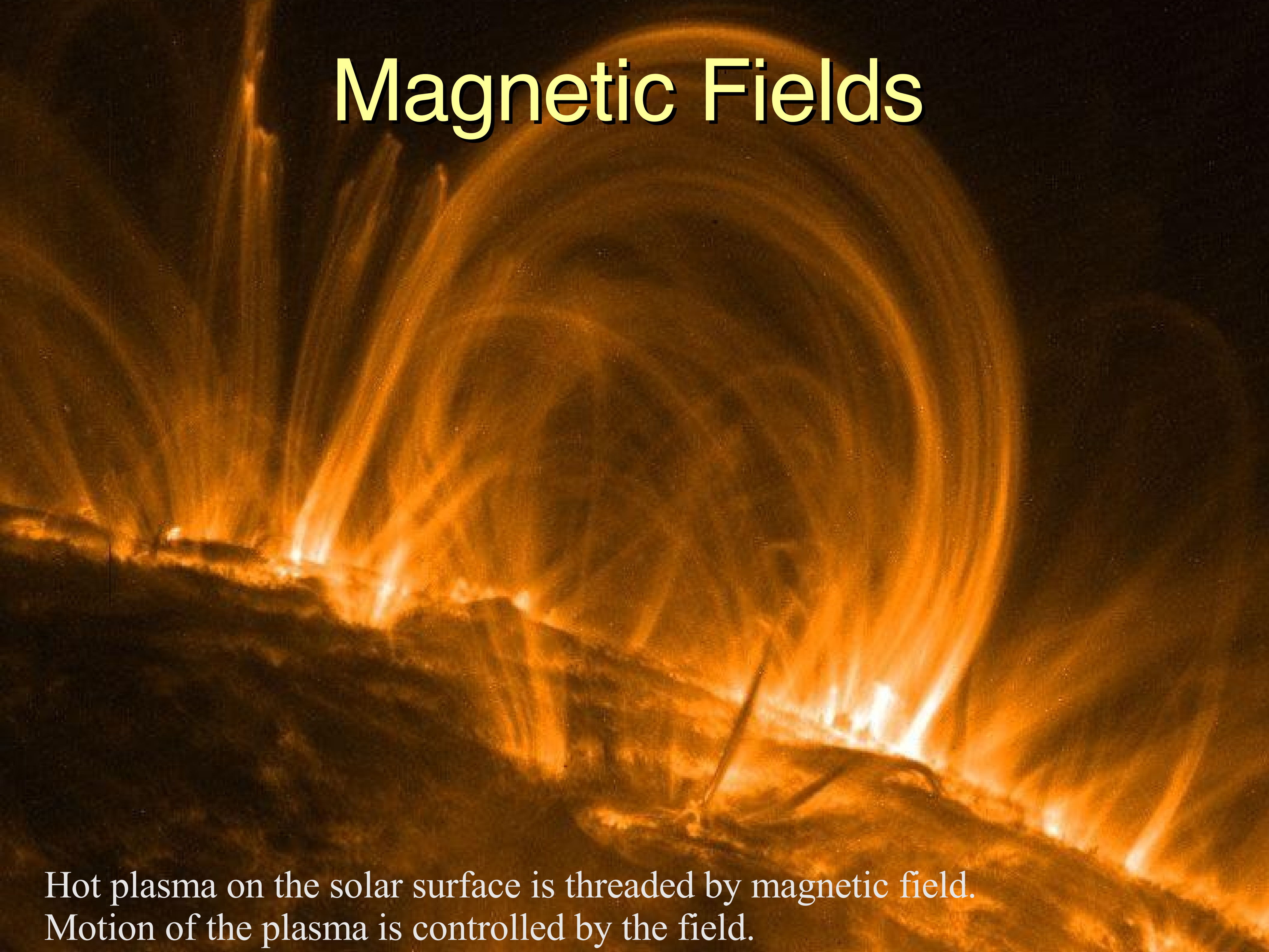
Crop-failures, starvations, uprisings, witch-hunting...

# The bubbling surface of the Sun

(outside the sunspots)

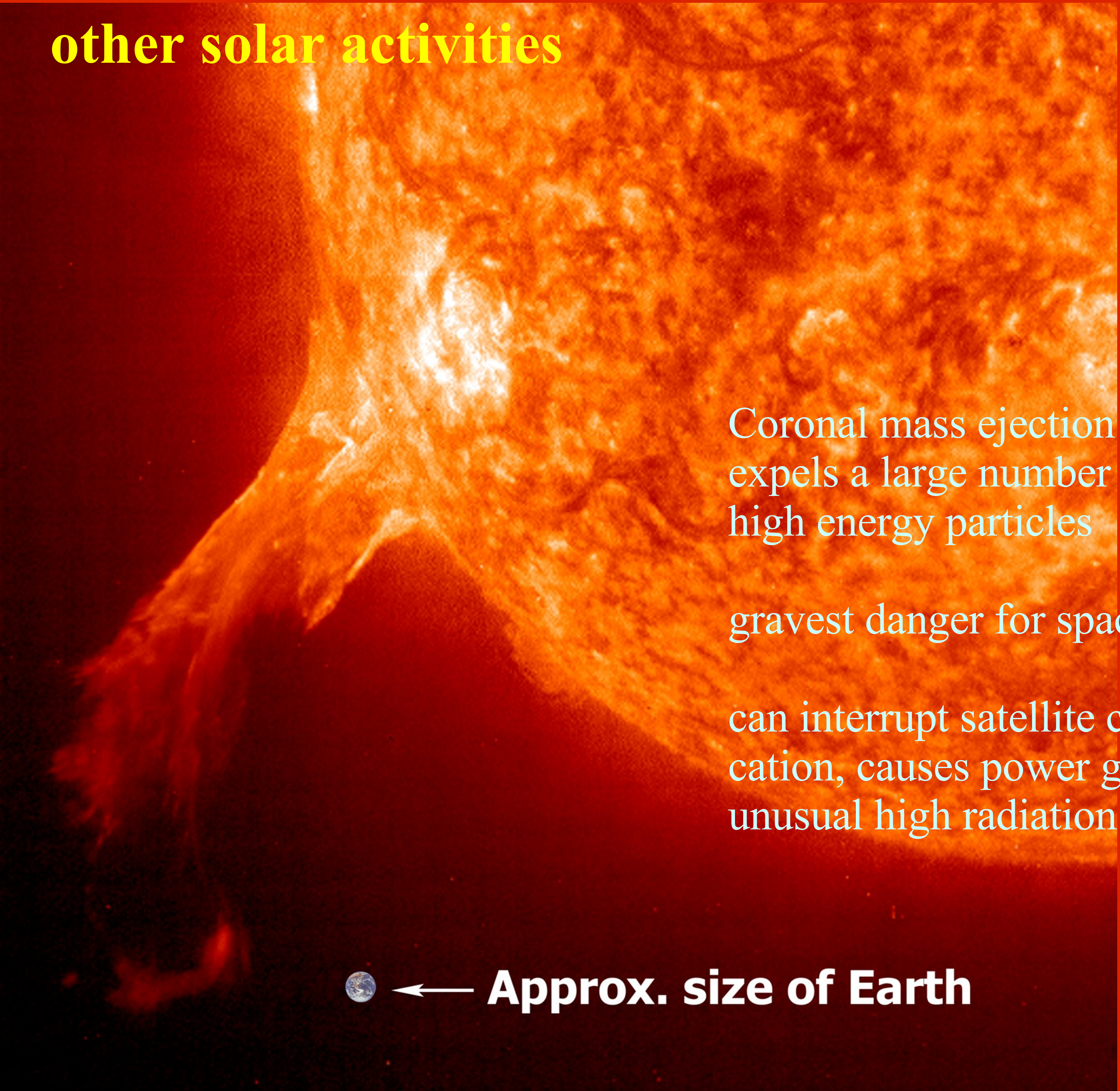
The solar surface is literally boiling.
Heat from below gets out in the form of 'convection'

# Magnetic Fields



Hot plasma on the solar surface is threaded by magnetic field.
Motion of the plasma is controlled by the field.

# other solar activities




Coronal mass ejection (CME) expels a large number of high energy particles

gravest danger for space travel

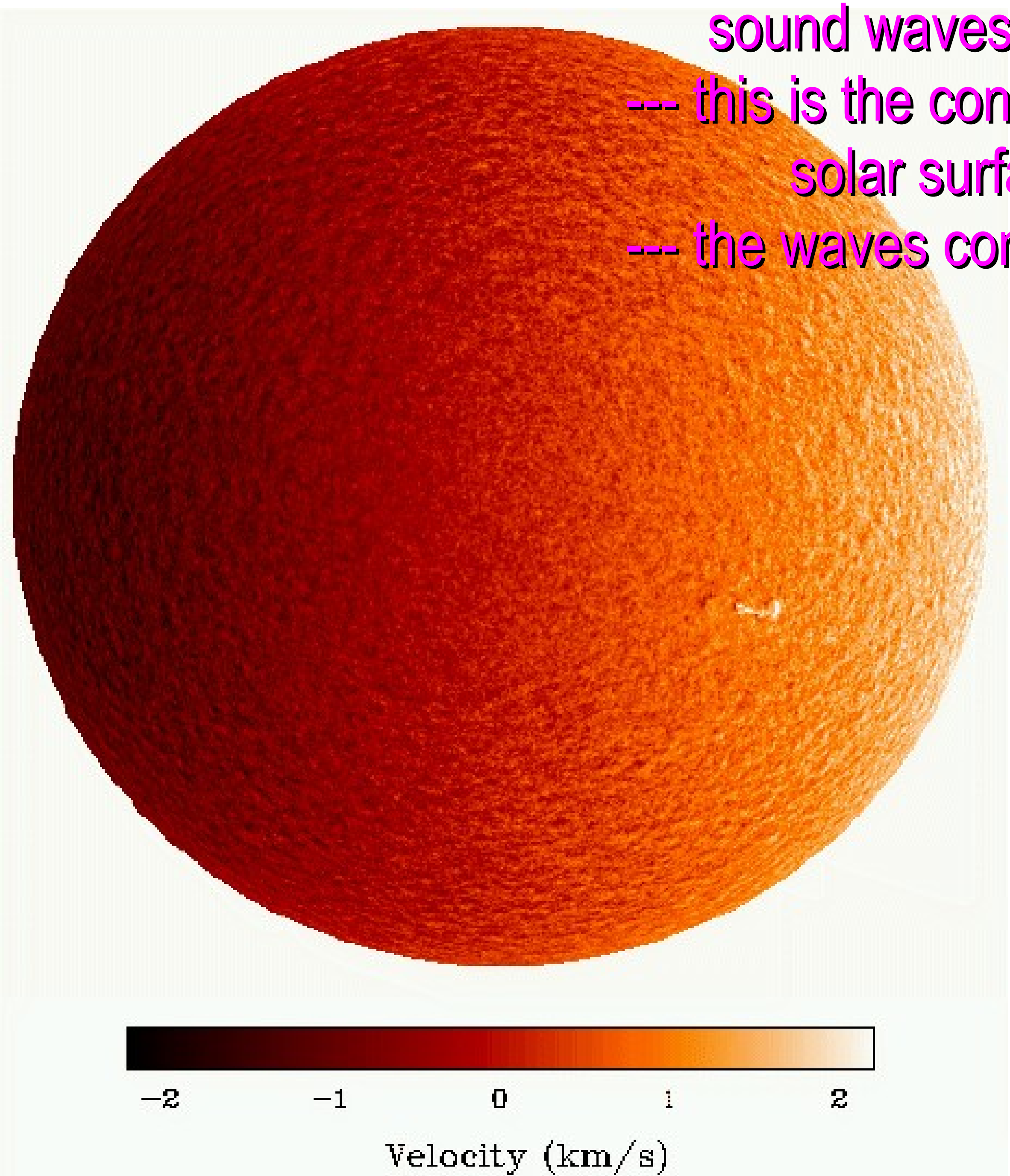
can interrupt satellite communication, causes power grid failure, unusual high radiation on Earth...

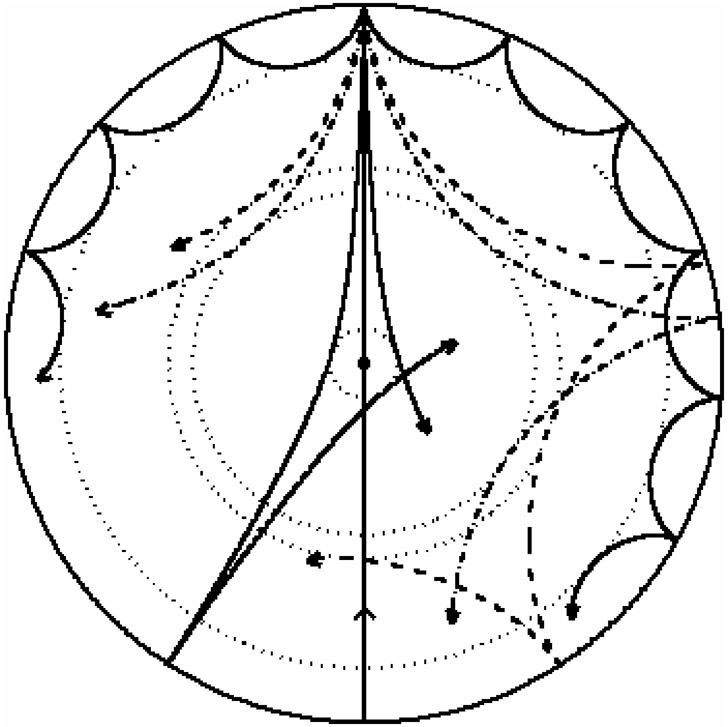
The entire Sun is also oscillating (solar oscillations)

--- something is “clapping” and produces sound waves inside the Sun (movie)

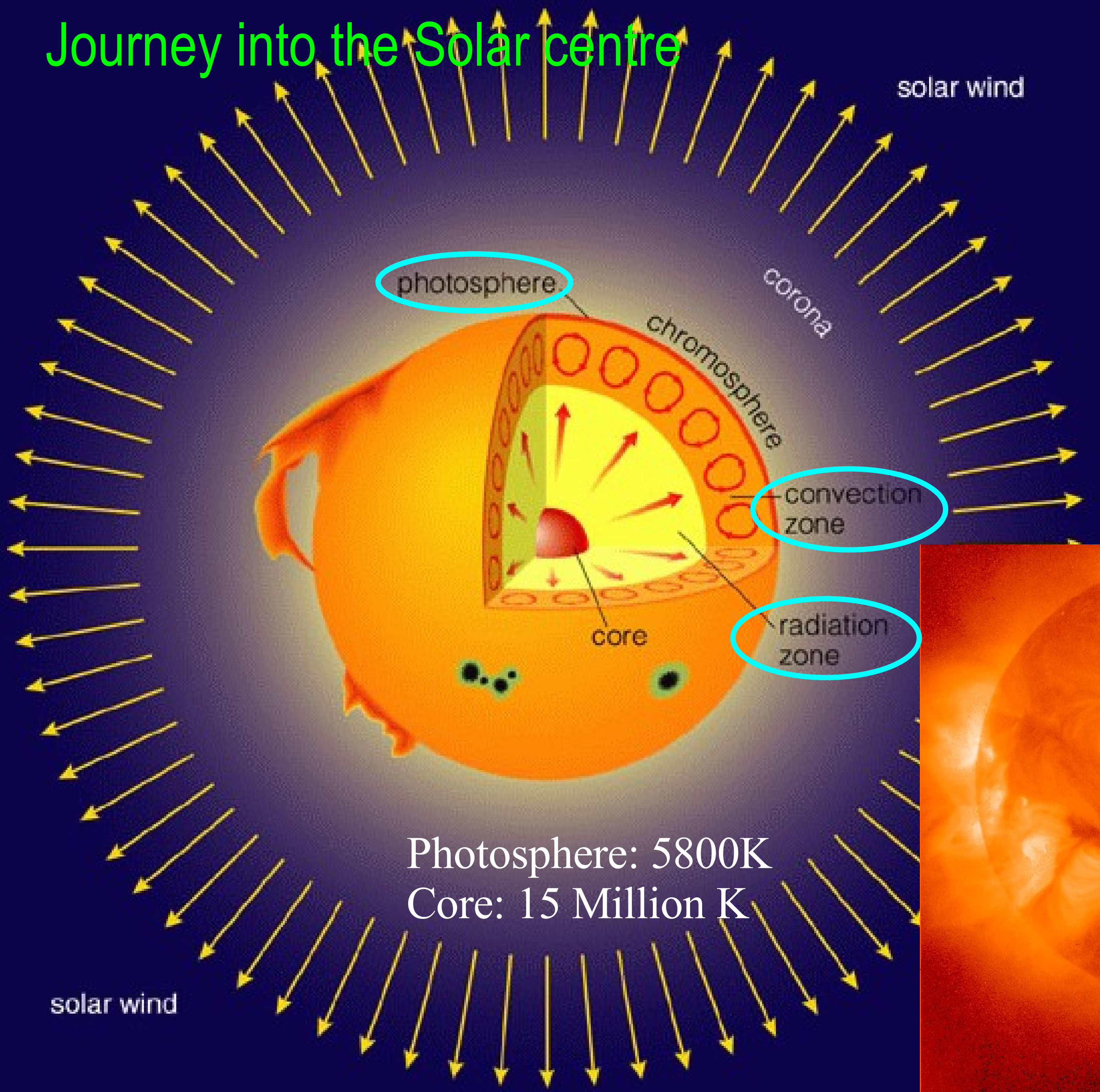
--- this is the convective motion near the solar surface

--- the waves come in all tunes

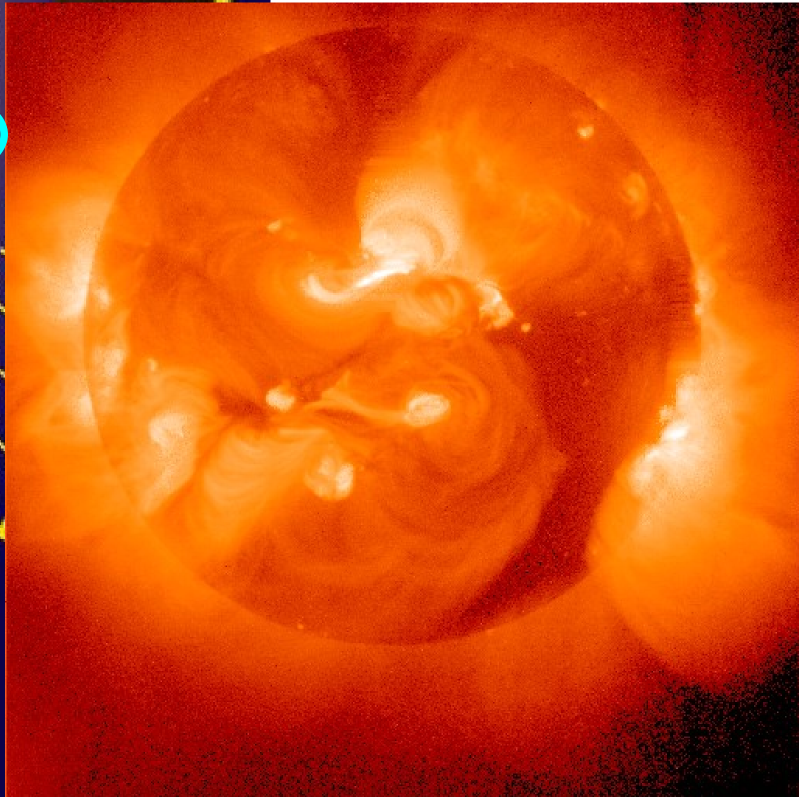


# Journey into the Solar centre




Photosphere: 5800K
Core: 15 Million K



# The concept of <u>pressure</u>

1. a lower layer has to support the upper layer from collapsing down
   *called 'hydrostatic balance' or 'gravitational equilibrium'*

2. as such, it needs to resist compression

3. the ability to resist compression is called 'pressure'


4. deeper layers have higher pressure *(larger accum. weight)*

4. hotter gas has a higher pressure, therefore deeper layer is hotter *(surface: 5800K, centre 15 million K)*

5. If this hot gas cools, gas above it will get pulled inward by gravity
   *(Earth atmosphere collapses a bit in winter)*

# Kelvin and the age of the Sun

## Kelvin's contraction theory

1. Some heat is lost from the Sun's surface

2. When some heat is lost, pressure decreases and gravity can squeeze the star together a little bit

3. This compression heats up the gas (Gravitational energy is converted into heat.)

The Sun continues the cycle, somewhat smaller and hotter.

Odd but true: The Sun's core heats up in response to energy *loss* at its surface!

*Courtesy of Ray Jayadwharna*

# Kelvin vs. Darwin

Charles Darwin in the first edition of *Origin of Species* (1859) argued for "incomparably vast" evolutionary timescales – billions of years.

William Thomson (Lord Kelvin): Derived *upper limits* on the age of the Sun and Earth.
1862: estimates the Earth is **100 million years** old
1897: revises this estimate downward to **25 Myr**

Darwin removes specific discussion of timescales in 3rd edition

Geologists & Paleontologists struggle to accommodate a shortage of time…

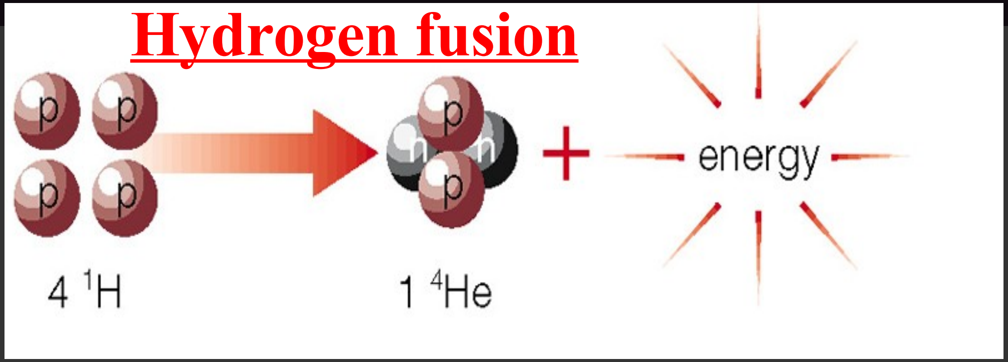
*Courtesy of Ray Jayadwharna*

# Why was Kelvin wrong?

**The Sun:** he did not know about nuclear fusion.

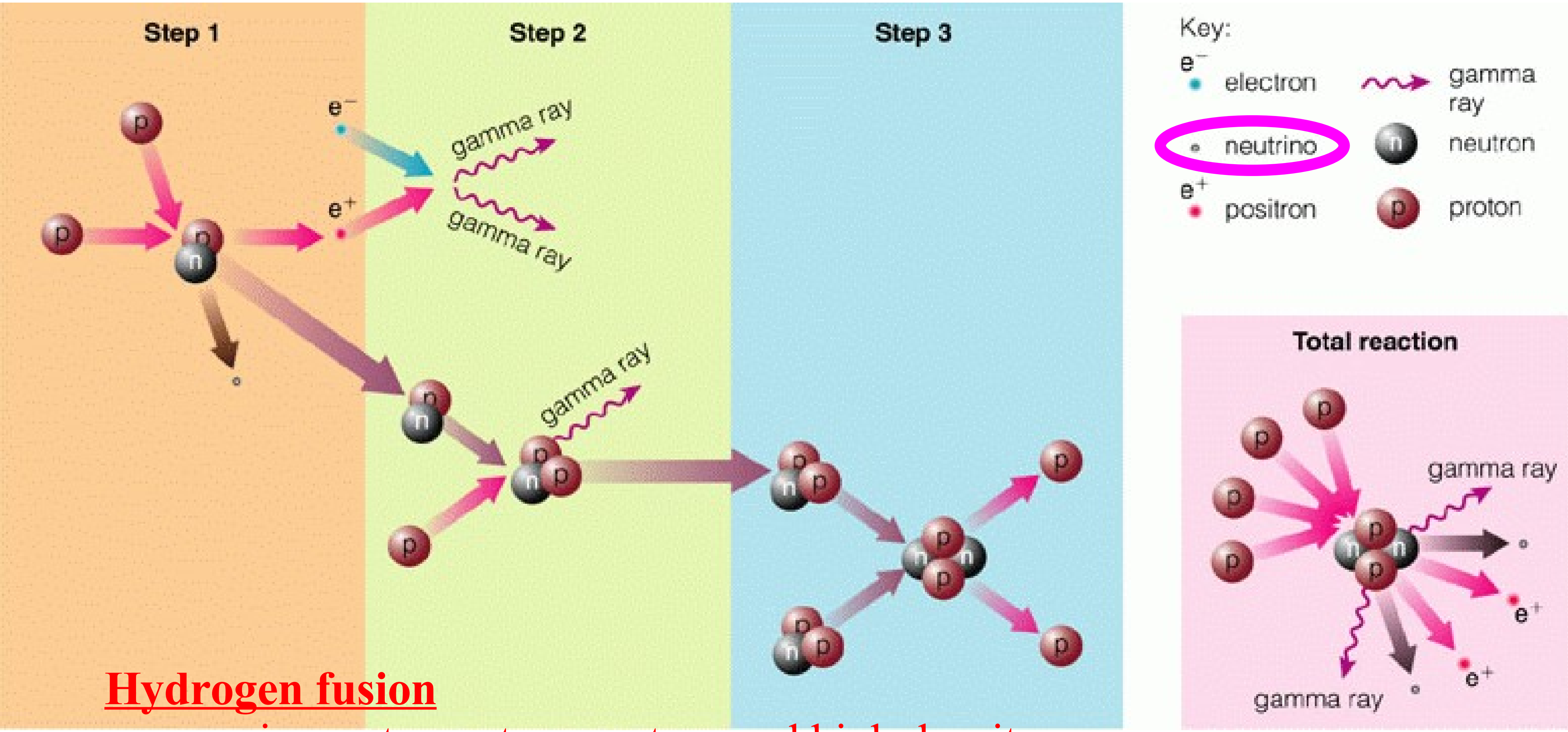
1905: Einstein derives $E = m\,c^2$

1920s: Sir Arthur Eddington notices that 4 protons are 0.7% heavier than a $^4$He nucleus (2 $p^+$ + 2 n) … or 1 part in 140 of the mass




Courtesy of Ray Jayadwharna

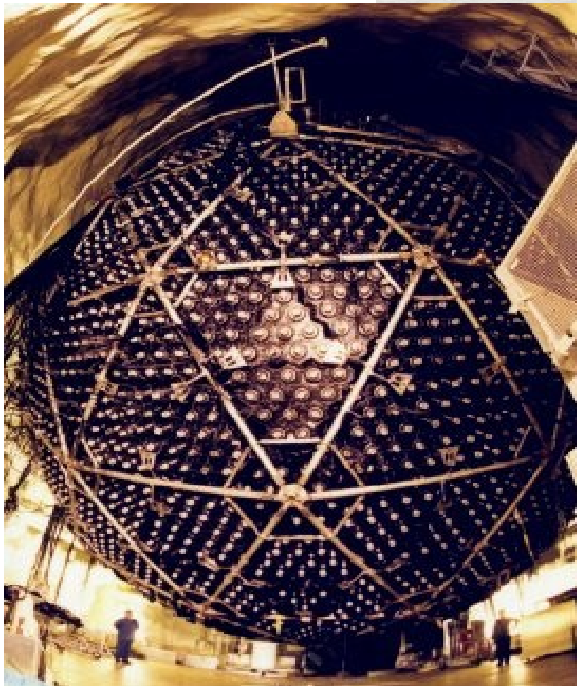
# Life would not be were it not for this reaction

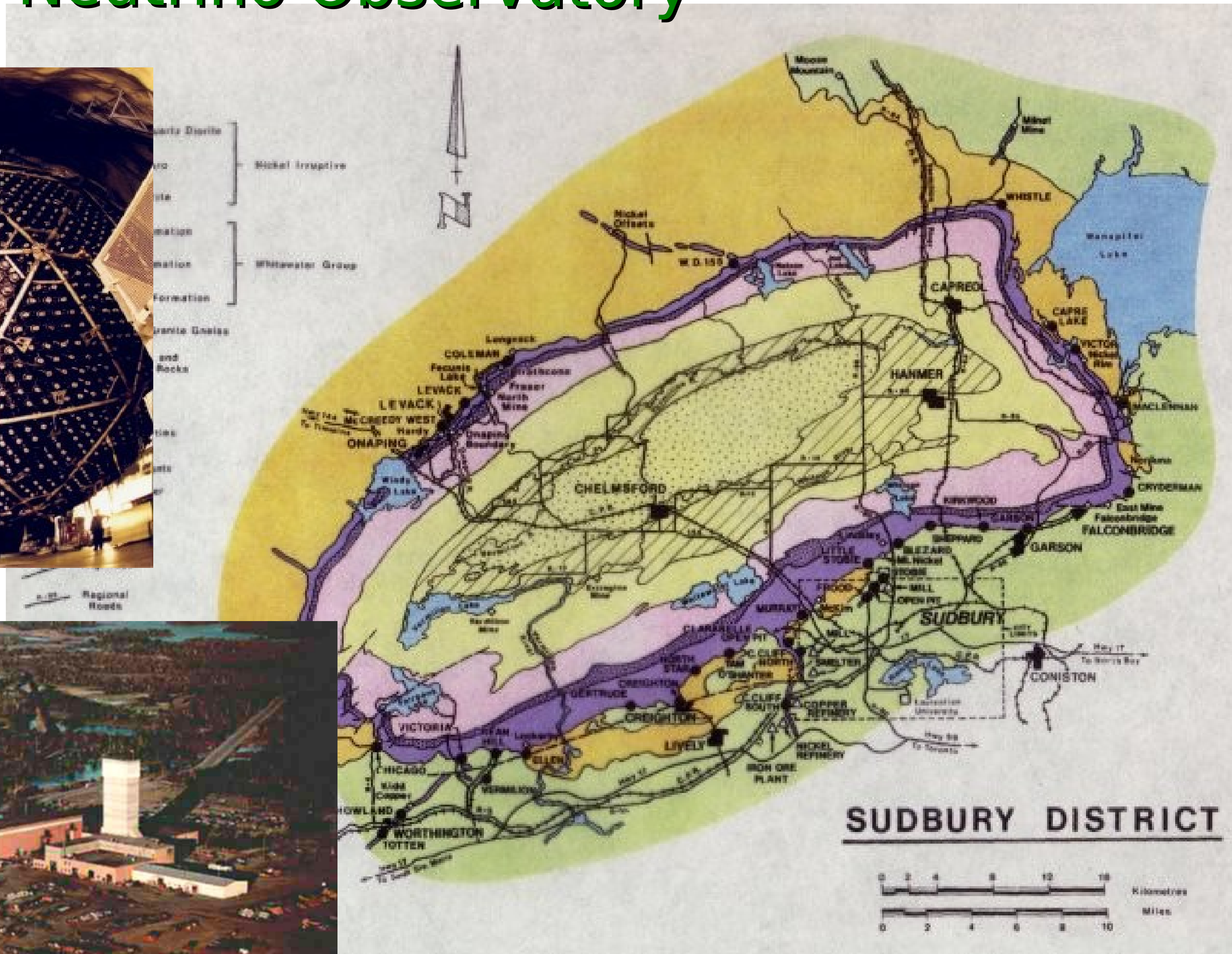



**Hydrogen fusion**

requires extreme temperature and high density
yet unreachable on Earth (the international fusion project)

# Sudbury Neutrino Observatory

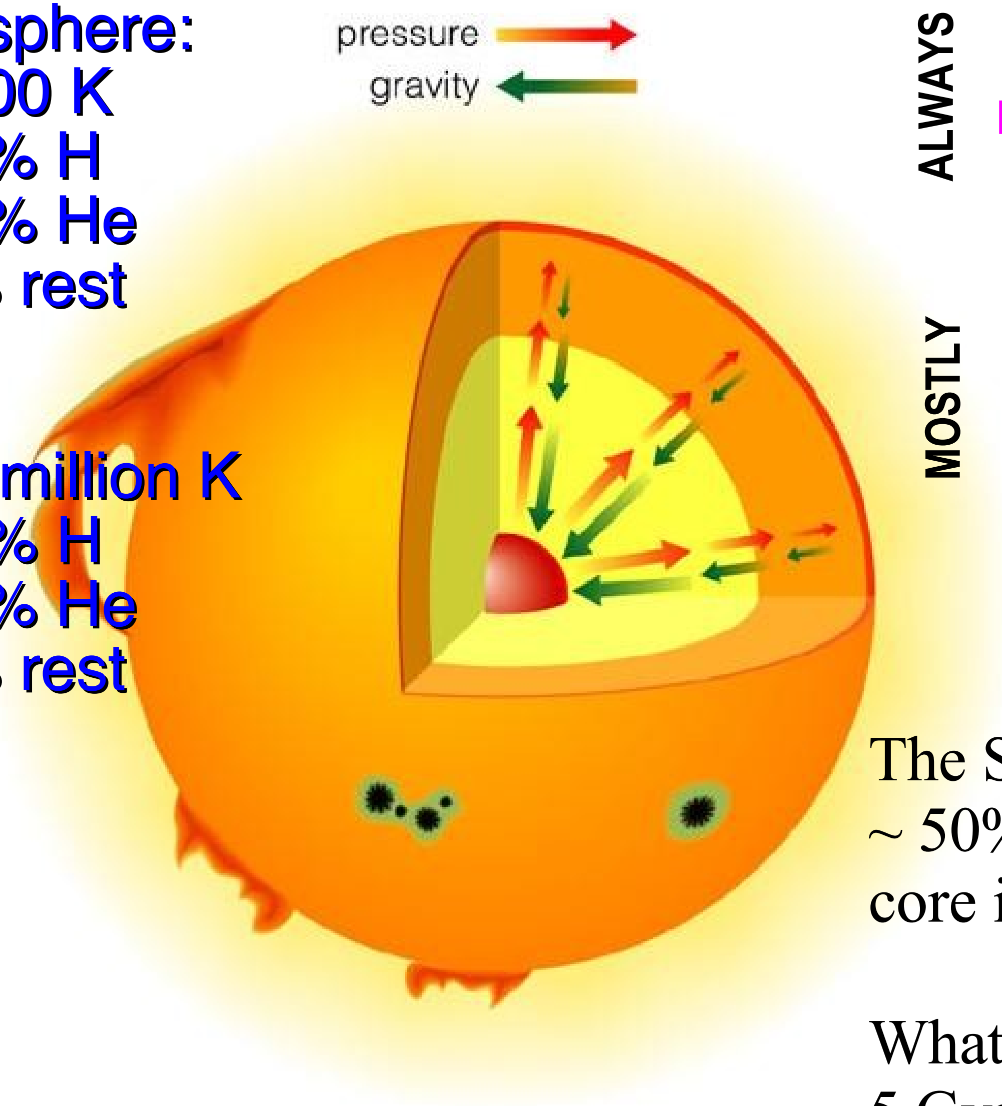





# Life of a star: a protracted battle with gravity

**Photosphere:**
5800 K
70% H
28% He
2% rest

**Core:**
15 million K
33% H
65% He
2% rest




ALWAYS

To support weight:

need high pressure

MOSTLY

⇒ need high temperature

⇒ will loose energy

⇒ need energy source

nuclear fusion

The Sun has converted ~ 50% of hydrogen in its core into helium (5 Gyrs)

What happens when, in another 5 Gyrs, hydrogen is exhausted?